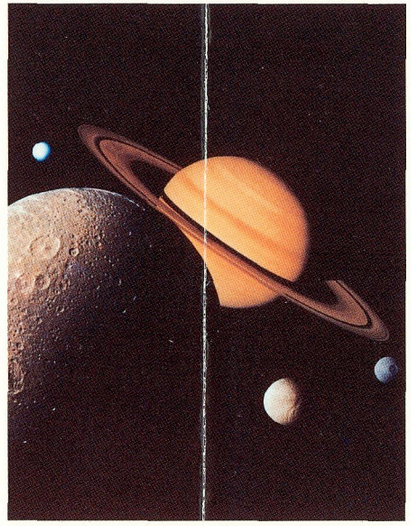
saturn: lord of the rings

Saturn, the sixth planet from the Sun, was the outermost edge of the known solar system for thousands of years. Saturn is one of five planets visible from Earth without a telescope. The Greeks called it *Chronos*, the name of their god of time. The Romans named it after *Saturn*, their god of agriculture, and devised a stylized scythe as Saturn's symbol.

Since the 17th century, when Saturn's dazzling, complex ring system was first observed by the Italian astronomer Galileo Galilei, the planet has stood as a symbol of the majesty, mystery, and order of the physical universe. In the past 20 years we have learned that Saturn is not the only planet with a ring system. All four of the giant gaseous planets of the outer solar system—Jupiter, Saturn, Uranus, and Neptune—have rings, but Saturn's ring system is the most extensive and brilliant. The origin of the rings is unknown, but scientists hope to uncover clues by studying the planet's history.



This Saturnian-system montage, created from Voyager 1 images, includes Saturn and four of its moons: Enceladus (upper left), Dione (in front of Saturn), and Tethys and Mimas (lower right).

During the formation of our solar system approximately 4.5 billion years ago, the primordial cores of the four giant planets formed in a frigid region of the *solar nebula* (the spinning cloud of dust and gas from which the Sun and planets formed) far from the vaporizing effects of the Sun. These icy cores grew quickly from their spinning *protoplanetary nebula* (the nebular region local to each planet) and gravitationally "swept up" much of the mass—most of it gaseous—present in the early solar system. Like the other giant planets, Saturn is thus a kind of "living laboratory" of the origin, dynamics, and evolution of the early solar system. Also like the other giants, its huge atmosphere has a story to tell.

We know that Saturn's atmosphere, like those of the other giant planets, features "zonal jets" (bands of atmospheric circulation) that race across the cloudtops in alternating east-west, west-east bands. The atmosphere is largely hydrogen and helium, with trace amounts of other elements. Electrical processes and heat from internal planetary sources enrich the layered chemical mix of the atmosphere, which probably transitions from superheated water near the core to the ammonia ice clouds we can observe at cloudtop. Saturn's atmosphere, like those of other giant planets, features storm structures similar to Jupiter's famous Great Red Spot, and near the poles of the planet there seem to be convective regions, which may be storms similar to terrestrial thunderstorms.

Our understanding of Saturn is intriguing but far from complete. It reflects centuries of astronomical observation and three brief spacecraft "flybys."

missions of discovery

At the dawn of the space age, 3 centuries of Earth-based astronomy had shown Saturn to have three rings—of unknown composition—and nine moons. Although Galileo was the first to see the rings (in 1610), it wasn't until 1659 that the Dutch astronomer Christiaan Huygens, using an improved telescope, observed that the rings actually are separate from the planet. In 1676, the French-Italian astronomer Jean Dominique Cassini first observed what appeared to be a division between the rings—now known as the Cassini division. Improvements in telescopy over the next 3 centuries revealed much about the mysterious planet: the banded atmosphere, the storm "spots," and a very apparent flattening at the poles, three features Saturn was observed to share with Jupiter.

The first two space missions to the outer planets were NASA's Pioneer 10 and 11, launched in March 1972 and April 1973, respectively. Pioneer 10 visited only Jupiter before heading out of the solar system, but Pioneer 11 not only visited Jupiter, but used the giant planet's gravity to accelerate it toward Saturn. Arriving at Saturn in 1979, after 6-1/2 years en route, Pioneer 11 gave us our first close-up look of the mysterious planet, discovering two new rings. One (the F ring) was observed visually; the other (the G ring) was inferred from data provided by electron and proton detection experiments on the spacecraft. Several moons of Saturn were also detected this way, before they were ever observed. The Pioneer camera determined that the Cassini division was in fact *(continued)*

the saturnian fleet

Spacecraft	Launch	Accomplishments
Pioneer 11 **(U.S.)**	4/5/73	*Flyby of Jupiter and Saturn.* Second spacecraft to the outer planets, after Pioneer 10. Passed within 22,000 km of Saturn's cloudtops (9/1/79). First images of polar regions. Discovered two new rings. Imaged Titan. Detected presence of internal source of heat in Saturn.
Voyager 1 **(U.S.)**	9/5/77	*Flyby of Jupiter and Saturn.* Passed within 125,000 km of Saturn's cloudtops (11/12/80). Sent back 17,500 color images. Detected four previously unknown moons. Measured extremely high wind speeds in Saturn's equatorial region. Detected "shepherding" moons flanking F ring and hundreds of ringlets in the A, B, and C rings. First images of D and G rings. Imaged five moons; detected surprising abundance of nitrogen in Titan's atmosphere. Measured Titan's size and near-surface atmospheric pressure.
Voyager 2 **(U.S.)**	8/20/77	*Flyby of Jupiter, Saturn, Uranus, and Neptune.* Passed within 101,000 km of Saturn's cloudtops (8/25/81). Provided detailed imagery of rings, including dynamic "spoke phenomenon." Measured ring thickness. Imaged intermediate-sized moons Mimas, Tethys, Dione, Rhea, and Enceladus. Further measurements and composition studies of Titan's atmosphere.
Cassini **(U.S./European)**	10/97	*Orbiter/Probe to Saturn and Titan.* Will encounter Saturnian system in June 2004. Will deploy instrumented Huygens Probe into Titan's atmosphere. Orbiter will make approximately 60 orbits through system over subsequent 4 years, studying Saturn, its rings, and its moons.

Note: Some images have been color-enhanced to bring out detail.

discovering

saturn

NASA

SOLAR SYSTEM EXPLORATION DIVISION

PAM-541
10/93

missions of discovery (cont'd)

populated by dark material in a faint ring. Pioneer 11 also discovered that Saturn has a strong magnetic field, 1,000 times stronger than Earth's, but only 1/20th that measured at Jupiter. Visible and infrared observations of Saturn revealed a surprising mix of thermal patterns among the cloud bands, suggesting internal processes yet to be understood.

The next spacecraft to visit Saturn were Voyagers 1 and 2, launched in the summer of 1977. Arriving in 1980 and 1981, respectively, Voyagers 1 and 2, having completed successful encounters with Jupiter, turned their instruments on Saturn, its rings, moons, and magnetosphere.

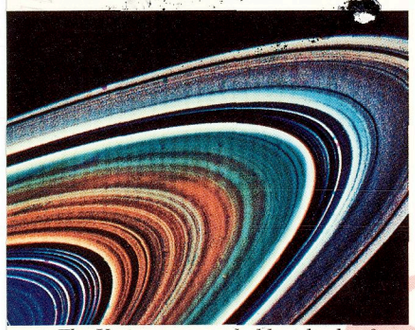
The ring observations were startling. The Voyagers revealed hundreds of ringlets within the major rings. Some ringlets were "braided," some had small moons flanking them (called "shepherding" moons), and all gave the impression of great dynamism. Shadowy "spokes" were seen to develop and dissipate in the rings. Ring-particles were found to be composed mostly of ice crystals, and to range in size from a few centimeters to a few meters. The overall thickness of the ring system was measured to be quite thin—only a few dozen meters in some places.

The Voyagers also studied Saturn's moons, and were surprised to find some covered with very smooth ice. These smooth, highly reflective surfaces suggest that there is some mechanism replenishing them with new material (old surfaces tend to be dirty and cratered), but the mechanism for this replenishment remains a mystery.

The Voyagers then sped on: Voyager 1 on its way out of the solar system; Voyager 2 to Uranus and Neptune. Scientists were left with an extraordinary set of data to study and interpret.

moons and rings

Today we know Saturn to have 8 major rings and 18 moons. The ring system comprises, in order from the innermost to the outermost, the D ring, the C ring (including the Maxwell gap), the B ring, the Huygens gap, the Cassini division, the A ring (including the Encke and Keeler gaps), and the F, G, and E rings. The Cassini division was shown by the Voyagers to be, in fact, several faint rings occupying most of the space between the Huygens gap and the A ring, and is therefore sometimes referred to as the Cassini *ring*—Saturn's eighth.

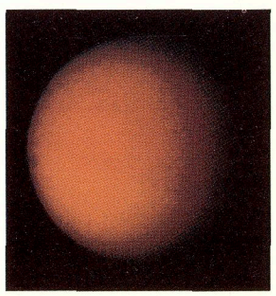


The Voyagers revealed hundreds of brilliant rings around Saturn. (Voyager 2 image)

The origin of the rings is unknown. They may be the remnants of moons destroyed by tidal interaction with Saturn's gravity. They may include remnants of comets that passed too close to Saturn and were likewise destroyed. The faint, tenuous E ring may be debris injected into orbit around Saturn by the moon Enceladus.

The Voyagers discovered four previously unobserved moons of Saturn, two of which are associated with the F ring. The shepherding moons Pandora and Prometheus seem to gravitationally "herd" the particles in the narrow F ring, and the effect of their gravities can be seen in braiding and clumping in the ring particles. Although each of Saturn's moons has a tale to tell, the moon that has held the attention of scientists most strongly is the largest—Titan.

Titan, with a radius of 2,575 kilometers is a bit larger than the planet Mercury. Titan was discovered by Huygens in 1655. In the 1940s, the Dutch astronomer Gerard Kuiper made the startling discovery that Titan has an atmosphere, surprising for a relatively small body so far from the Sun. When Voyager 1 flew by Titan in November 1980, we learned that Titan is perpetually obscured by a complex, primarily nitrogen atmosphere—similar to what we believe Earth's to have been like in the early stages of its development. Titan's atmosphere was also found to contain large amounts of organic (carbon-based) compounds, suggesting that primordial gases had been trapped in the planet's ices as it formed, and were released over time into the atmosphere. Further study of Titan promises to reveal much about planetary formation, and perhaps about the primordial Earth as well.

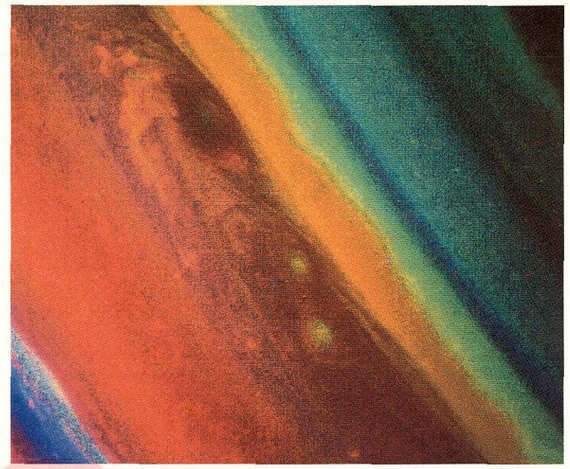


Titan, Saturn's largest moon, is shrouded by a thick nitrogen atmosphere that could be similar to what Earth's may have been like long ago. (Voyager 2 image)

unanswered questions

Saturn and its rings and moons hold clues to the origins of our solar system. The icy matter in Saturn's rings and icy satellites is believed to mirror the composition of Saturn's protoplanetary nebula. A more detailed study of the rings, therefore, will reveal something about the material from which Saturn formed and evolved. Saturn's atmospheric phenomena also need to be studied further. The planet's zonal jets are among the fastest moving in the solar system. Why? Why do they circulate predominantly west to east, instead of in a more balanced system, as on Jupiter? Is there something going on in the interior of the planet that is driving the jets this way?

Titan, too, holds its mysteries. What goes on beneath Titan's organically rich, primordial Earth-like atmosphere? Radar observations from Earth suggest that there may be continents on Titan. What planetary processes could occur in such a cold environment, where water ice is so cold it has the properties of rock? These are among the questions to be addressed by the next mission to Saturn.

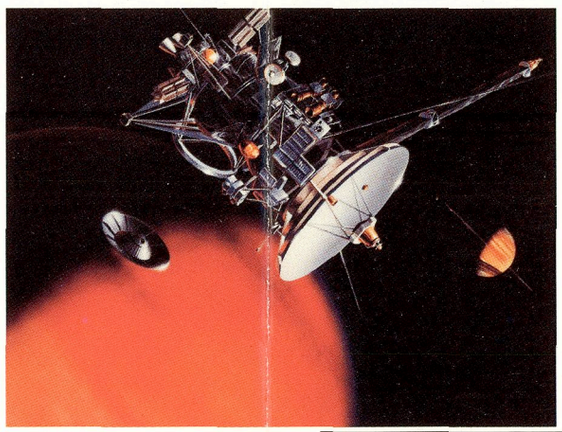


Although the cloud system associated with the western-most spot (shown here) is part of a 33 mph western flow, the spot itself moves eastward at a rate twice as fast. (Voyager 2 image)

the cassini mission

Cassini, a joint U.S.-European orbiter/probe mission to Saturn and Titan, will be launched in October 1997, arriving at the Saturnian system in 2004. Cassini's 4-year scientific mission at Saturn is dual: to complete a multispectral, orbital surveillance of Saturn, and to investigate Titan. The U.S. Cassini Orbiter, during its 60-orbit tour of the Saturnian system, will measure the planet's magnetosphere, atmosphere, and rings, and observe some of its icy satellites and Titan during close flybys. The Orbiter investigation of Titan will be augmented by an instrumented European probe—called the Huygens Probe—that will be dropped through Titan's dense atmosphere. If it survives its landing on Titan, the Huygens Probe will send back surface readings before shutting down.

The Cassini data will be a major contribution to our scientific modeling of planetary atmospheres, important to our understanding of the evolution of Earth's own atmosphere. The Cassini Orbiter's multiple close flybys of Saturn's icy satellites also will provide insight into the nature of the population of small planet-like bodies that may once have been prevalent in the outer solar system.



The Cassini mission is fully international in scope. The Huygens Probe is being provided by the European Space Agency, and elements of three of Cassini's science instruments are being provided by the Italian Space Agency, as is the Orbiter's high-gain antenna. When Cassini is en route to Saturn in 1997, it will have been propelled not just by a rocket engine, but by the history and best intentions of cooperative human study of the outer solar system.

The Cassini spacecraft will arrive at the Saturnian system in 2004. (artist's conception)

saturn

Namesake & Symbol	Roman God of Agriculture ♄
Mean Distance from Sun	1,429.4 million kilometers
Period of Rotation	10.656 hours (= 1 Saturnian day)
Equatorial Diameter	120,536 kilometers
Equatorial Inclination to Orbit	26.73°
Gravity	9.05 m/s^2 at 1-bar pressure level (i.e., pressure equivalent of Earth's surface)
Atmosphere:	
Main Component	Hydrogen and helium
Pressure at Outer Edge of Core	At deduced radial location of outer edge of liquid core, pressure deduced to be 12 Mbar
Temperature Range	At deduced radial location of outer edge of liquid core: 12,000 kelvin; thermospheric: 420 kelvin; at cloudtop: 95 kelvin
Moons (18)	In ascending distance from planet: Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Mimas, Enceladus, Tethys/Telesto/Calypso, Dione/Helene, Rhea, Titan, Hyperion, Iapetus, Phoebe (moons combined by slashes are co-orbital; i.e., they share an orbit)
Number of Rings (7)	In ascending distance from planet: D ring, C ring, B ring, A ring, F ring, G ring, E ring
Orbital Eccentricity	0.056
Orbital Inclination to Ecliptic	2.49°
Magnetic Field Density at Equator	0.21 Gauss (at 1-bar pressure level)

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